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**BEYOND WORD PROCESSING: USING AN  
INTERACTIVE LEARNING ENVIRONMENT  
TO TEACH WRITING**

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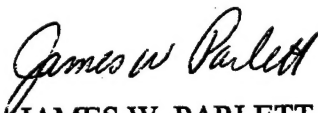
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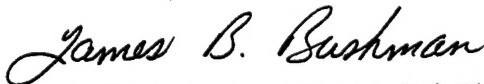
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13. ABSTRACT (Maximum 200 words)  This study examines whether computer-aided instruction that explicitly models the process of composing for basic writers is more effective than traditional classroom instruction. Three objectives guided the research: (1) to determine the basic quality of essays from the treatment and the control group using standard, holistic rating methods, (2) to infer cognitive development by measuring improvement along four separate measures using an analytic scale, (3) to determine whether initial aptitude was a factor in performance differences. Eight-hundred and fifty-two ninth-grade English students (423 in the control group and 429 in the treatment group) completed a 40-minute transactional writing sample at the beginning and at the end of a 16-week semester. The results show that the group using a computerized "cognition facilitator" outperformed the group taught only in the traditional classroom both on the holistic and on the analytical measures. Additionally, when the population was partitioned to reflect initial ability, the treatment group in the lower segment showed marked improvement, whereas the high-end segment of the treatment group produced no significant gain. When partitioned in the same manner, the high-end for the control group degraded in performance, while the lower-end control improved both on the holistic and the analytic measures.				
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## PREFACE

R-WISE ( Reading and Writing in a Supportive Environment) is part of a 7-year Air Force effort -- the Fundamental Skills Training project -- to design, build, evaluate, and transition advanced computer-aided instruction to the education community. This research was done while Patricia Carlson was an associate at the Armstrong Laboratory, Human Resources Directorate, Intelligent Training Branch, Brooks AFB, TX, on leave from Rose-Hulman Institute of Technology. This article does not necessarily reflect the opinions or policies of the U.S. Air Force or any other government agency.

This report describes R-WISE 1.0 and presents the results of an initial evaluation of the software. Many people contributed to the development of R-WISE. The authors express their gratitude to the high school teachers who served as subject matter experts; the programmers who developed the software; and the research assistants who tabulated the data for the pilot study. We especially acknowledge the generous sharing of time and talent and continued support of the following individuals: Dr. Wes Regian, Senior Scientist for the Intelligent Training Branch (AL/HRTI); LtCol Jim Parlett, AL/HRTI Branch Chief; Dr. Kurt Steuck, the Fundamental Skills Training Project Manager; and Ms Teri Jackson, who oversaw the implementation of R-WISE at 10 sites in five different states.

# **Beyond Word Processing: Using an Interactive Learning Environment to Teach Writing**

## **1.0 Process Models of Writing and Cognitive Development**

The past three decades of inquiry into the writing process have yielded a greater understanding of prose composition as a cognitive act. Hayes and Flower pooled their talents as cognitive psychologist and rhetorician (respectively) to author a series of groundbreaking articles that present a flowchart model of composing based on hierarchical decision-making, deconstruction of the tasks, and feedback loops that monitor and regulate the interactions among (1) task environment, (2) long-term memory, and (3) goals and plans (Flower & Hayes, 1980; 1981; Hayes & Flower, 1983). Other researchers have also made significant contributions to a descriptive model of the cognition involved in writing. Bereiter and Scardamalia (1987) draw upon years of empirical research to extract the notion of *intentional instruction*, or explicitly teaching writing as a process of setting goals and achieving those goals through schema-driven strategies and metacognitive awareness. Collins and Gentner (1980) champion a fully-specified theory of composing so that the model can be extended into computer technology, particularly artificial intelligence. Rose (1984) as well as Beaugrande (1984), on the other hand, argue for a less hierarchical, more situational model similar to the notions of contingency management and the idea of opportunism presented by the Hayes-Roth's (1979) investigations into the nature of planning.

Although there is no unified field-theory of composing and no single model has gained enough acceptance to displace others, any process description of writing takes as a given that good writing is the product of good thinking and that good thinking consists of powerful, insightful, and systematic forms of intellectual activities. While dismissed by some traditional rhetoricians (e.g., Steinmann, 1982) and minimized by proponents of the social interaction view of composing (e.g., LeFevre, 1987), instruction that emphasizes cognitive development as the foundation for writing gained support in the 1980s (D'Angelo, 1980; Flower, 1981; Hillocks, 1982). Though differing in some of their features, these pedagogies essentially wed the forms of inquiry to the forms of discourse -- or the methods of formulating thoughts with requirements for textual presentation of ideas. Recognizing both the cognitive and affective sides of learning, these approaches foster analytical reasoning as well as creative reconstruction of information and are quite complex in the fullness of their concerns. For example, cognitive models of composition instruction encourage interactive rather than passive learning by guiding the student through higher-order considerations about writing, such as allocation of attention, inferential reconstruction of previously known facts and observations, inductive and deductive reasoning, interpretive elaboration, and the like.

For this study, we draw from the research of Bereiter and Scardamalia (1987) to give a cogent description both of the process and of the resultant product of novice and expert writers. Inexperienced writers practice a form of writing that Bereiter and Scardamalia

call *knowledge telling* (1987). Their inadequacy is not necessarily a result of poor spelling, vocabulary, grammar, verbal fluency, syntax, paragraphing, or other such production skills. Knowledge telling is characterized by (1) a simple task execution involving only limited planning and mental engagement, (2) production methods adapted from oral abilities, (3) organization patterns based on almost free-association or simple narration, (4) development that contains large chunks of irrelevant information or elaborations based on simple descriptions, and (5) an egocentric perspective. The antithesis, *knowledge transformation*, as practiced by good writers, is characterized by (1) guided planning and situational diagnostics, (2) rich mental representations of text possibilities for a wide range of scenarios, and (3) a robust *executive control program* or metacognitive self-prompting for allocating mental resources and for handling the tremendous cognitive load of verbal composition. From Bereiter and Scardamalia's (1987) descriptions both of the process and of the products for novice and expert, we have extracted four features of writing -- each of which represents a cluster of intellectual activities that manifest themselves as qualities of good writing. Although general, these features are sufficiently explicit to be testable.

*Abstraction* -- Experienced writers cluster specifics within a propositional frame-of-reference based on similarities, differences, likely outcomes, or proximity in time and space. Much of writing requires the writer to move from part to whole, or to draw from a body of evidence some inference or enumerative generalization about the body of observations. Though related to inductive reasoning, these intellectual operations might also be described as classificatory reasoning, synthesis, or inferencing.

*Elaboration* -- While experienced writers may have a variety of strategies for discovering appropriate content for the paper, they also have filtering mechanisms for selecting only those ideas appropriate for the audience and the purpose of the paper. A less-accomplished writer may lack the rhetorical awareness necessary for pruning and placing ideas within the paper. These writers practice a kind of *memory dump* when generating discourse. While they may include a number of separate ideas in their paper, the text has a superficial, canned, or random quality to it.

*Focus* -- Advanced writers are adept at establishing a purpose while at the same time providing a rich texture of detail. They do this by appropriately foregrounding ideas of interest while backgrounding contextual elements. Effective writing is more than correct lexical and syntactic manipulations. Connected discourse produces in the reader a sense of *centeredness*. This sense of *aboutness* is derived from the writer's ability to integrate concepts in the text. Focus is a product of intentionality (a goal or motive underlying the discourse) and of sustained point-of-view (a consistent perspective on a topic).

*Sequence* -- Expert writers formulate relationships of ideas in their minds and then convey these connections over large blocks of text through devices for coherence and cohesion that may be as simple as using transition words or as complex as interweaving a *given* in one sentence with the *new* in a subsequent sentence. This degree of logical organization is one feature that separates written text from spoken discourse. Organization is established



on the paragraph level by indicating relationships or connections among the individual sentences making up the discourse unit. Common patterns are problem-solution, cause-effect, or chronological order. Sequence can also be signaled by transitional devices that integrate sentences in such a way as to orient the reader and indicate a movement of meaning in a systematic way.

## **2.0 Mediating Cognitive Development through External Representation**

Extending psychological models of writing into effective classroom enactments has proven difficult. Though models help to identify the components of writing, the process is not linear and teaching is not as simple as providing instruction for each component and then putting the parts together. At the heart of the matter seems to be a kind of paradox. Accomplished writing requires considerable finesse in higher-order intellectual activities: critical thinking as a precursor to knowledge; judgment as the foundation for decision making; and self-confidence as the initiator of self-monitoring. Unfortunately, novice writers are so overwhelmed by the heavy demands of the process that they seldom are able to exhibit -- even on a rudimentary level -- these higher-order activities. Thus, they are precluded from working with the very same intellectual activities that would make them better writers.

### **2.1 Computers and Intelligence Amplification**

What is needed to help weak writers handle the cognitive overload is an instructional system that serves as a *procedural facilitator*. This term is used by Vygotsky (1978) to explain the cognitive mentoring and developmental dynamics that occur between master and apprentice and between peers during collaboration. Salomon (1988) and Zeller-mayer, Salomon, Globerson & Givon (1991) use the term to indicate that computer technology can serve as a peripheral brain for the fledgling student and provide the scaffolding that allows the novice to practice the more robust problem-solving behaviors of an expert. In brief, such a procedural facilitator for composition would:

- Ease demands on short-term memory and help to focus attention on strategically important aspects of writing.
- Guide the inculcation and self-initiation of higher-order processes (metacognition) which the novice writer is unlikely to activate without prompting.
- Model explicit, strategic intellectual processes so that the fledgling student avoids what Collins & Gentner (1980) have termed *downsliding*, or becoming increasingly entangled in lower and lower levels of mental actions, finally concentrating all attention on such things as spelling, grammar, and sentence construction to the exclusion of larger concerns in the process.
- Mediate transitions from abstract thoughts to symbolic representations. Smith & Lansman (1989) conceptualize composition as an activity that takes place in three modes: thinking, organizing, and adapting. Each mode has its own set of goals,

processes, and constraints. What is needed, according to these researchers, is a set of visual workspaces that help the novice writer to gracefully move through the various state-transitions inherent in moving from thoughts to finished text.

- Provide embedded strategic models for higher-order cognitive activities (such as discerning patterns in bodies of information, decision-making, staged problem solving, analysis, synthesis, and inferencing).

Pea (1985), Perkins (1985), and Salomon (1988, 1993; Salomon, Perkins, & Globerson, 1991) make a compelling case that some types of computer applications not only facilitate a task's accomplishment but also help the user to internalize profound strategies for later performance of the same or similar tasks, without the presence of the technology.

Pea (1985) makes a distinction between *amplification* and *reorganization* in examining the effects of cognitive technologies. Defining cognitive technology as "any medium that helps transcend the limitations of the mind, such as memory, in activities of thinking, learning, and problem solving" (p. 168), Pea starts with an historical perspective and reviews the effects of literacy on cultures. Certain highly-designed artifacts of literacy have the power -- over a broad expanse of time -- to change human patterns of thinking. Goody (1977) and Eisenstein (1979) show that evolving textual conventions and the widespread availability of printed materials facilitated sophisticated mental operations, such as comparison and contrast.

From a less sweeping perspective, however, not all cognitive amplifiers have a lasting effect on the user. Citing Cole and Griffin (1980), Pea notes that a child can extend her short-term memory with paper and pencil by writing down a long list of words. The short-term memory is amplified in this single instance, but the child's mental capacity has not been improved or altered -- unless the paper and pencil somehow prompt the child to *chunk* the words in more easily processed clusters. In short, cognitive tools that have been carefully designed to move beyond mere conveniences will teach strategies for mental activities and -- rather than deskilling -- leave their users better off for having engaged the tool.

Two specific examples make these claims for the efficacy of the cognitive tool more definable. Pea (1985) uses the electronic spreadsheet as "... an illustration of computer technologies that can reorganize, and not merely amplify, mental functioning ..." (p. 170). Therefore, examining the cognitive design features of an electronic spreadsheet provides us with a point of departure. First, the electronic representation recaptures all the features and functionality of the paper ledger. A two-dimensional array displays categories and attributes, creating individual cells for the placement of data. Even this static ordering enables various forms of complex intellectual activity -- such as inferencing and categorical reasoning. Placing this representation in electronic form adds new dimensions: now the user can dynamically manipulate data in each cell and watch the impact of change on other elements of the system. This, contends Pea, changes the level of engagement between the information and the user. Instead of merely entering data, the user is

empowered to perform financial modeling, forecasting, and other forms of systemic and predictive thinking. Recent empirical studies support Pea's claims that using the tool elevates the user's understanding of the system in ways that both endure and generalize, even without the presence of the tool (Guster & Batt, 1989; Ryba & Anderson, 1990; Schiffman, 1986).

Our second example, the abacus, demonstrates how a non-western, non-computerized device can mediate cognitive reorganization. Stigler, Chalip, & Miller (1986) review a series of four studies showing that "... abacus training result[s] in qualitative changes in children's representations of mental calculations through development of a 'mental abacus.' ... Abacus training was found to affect both calculation skills and conceptual knowledge of the numeration system" (p. 447). In other words, these studies suggest that achieving a high level of skill (both speed and accuracy) in performing arithmetic calculations with an abacus results in enhanced cognitive abilities that can be attributed to practice with the device rather than factors such as socioeconomic status, ability, and previous mathematical knowledge.

Miller and Stigler (1991) studied abacus use as an example of research questions inherent in a whole category of representational systems. The abacus has utility in that one manipulates the device to complete specific, well-defined mathematical calculations. However, in mastering the tool, one also gains insights into the conceptual dimensions of the domain. In other words, students who had reached a level of proficiency with the abacus are also better able to answer sophisticated questions about number theory than a set of matched controls who had no exposure to the abacus. Within a wider context, the abacus as a reorganizer of cognition could lead to questions of minimalism: How small and simple can a device be and still leave a *cognitive residue* by reorganizing mental abilities? Abacus studies show that even within non-computer examples, cases exist of a simple but eloquent teaching device not only having a pragmatic result but also a conceptual effect.

## **2.2 The Cognitive Architecture of R-WISE 1.0**

Perkins (1986) extracts the notion of the *thinking frame* from the more abstract concept of schema theory. Perkins offers the following definition and explanation:

[A] *representation intended to guide the process of thought, supporting, organizing, and catalyzing that process.* This representation may be verbal, imagistic, even kinesthetic. When well-practiced, it need not be conscious. A thinking frame, in order to organize our thinking, includes information not only about how to proceed but when to proceed in that way (p. 7, italics in the original).

In practice, thinking frames occur in a number of different domains. Their form spans a gamut from simple (but powerful) mnemonic devices for extending the working memory to rich mental models that foster expert behaviors by invoking appropriate strategies,

conserving and allocating mental energies, and orchestrating steps in staged problem-solving techniques. In the realm of problem representation, John Hayes (1981) notes the utility of visualizations (such as matrices) to delimit the problem space and to facilitate *search* in a complex situation. As an example, Jones, Amiran, & Katims (1985) found that using a grid to encourage name-and-attribute clustering aided in recall and systematically produced effective compare-and-contrast type essays in a study of young adults. The rich body of research into mental models and instructional design (Gentner & Stevens, 1983; Kieras, 1988) suggests that highly-complex, multi-dimensional intellectual activities can be represented so as to help the novice activate and amplify specific expert strategies. For example, Gentner & Gentner (1983) found that the types of thinking people could do about electrical circuits depended on what kind of analogy (teeming crowds or flowing water) was used to represent the system and -- consequently -- the inferences these metaphors enabled.

Our software -- Reading and Writing in a Supportive Environment (R-WISE 1.0) -- provides scaffolding and visual algorithms that gently guide the writer through multi-staged intellectual activities. The software encourages students to practice powerful strategies for composing in a computer-mediated environment that fosters guided-inductive learning and ensures mindful engagement in the task. R-WISE 1.0 enables the internalization and self-initiation of higher-order processes and metacognition, which the novice writer is unlikely to activate without external prompting. The entire R-WISE 1.0 learning environment is made up of three sets of adaptive workspaces, each mediating the entire writing process but focusing on the strategies and self-regulative awareness characteristic of one of three domains (1) finding ideas, (2) transitioning ideas into prose, and (3) refining both ideas and text into final documents.

*Cubing --The Invention Tool:* Loosely based on Bloom's taxonomy (1956), this workspace uses a graphical representation (a six-sided cube) to depict complex mental operations. (The idea of a cube as a mnemonic for power perspectives on a subject show up in many traditional classroom instructional techniques.) This guided brainstorming tool helps student writers to generate and focus ideas while they work through a systematic exploration of their subject. Students generate a series of notecards for each selected perspective (side of the cube): describe, compare, associate, apply, analyze, and argue. This process modeler helps to bootstrap comprehension by reifying a process for (1) extracting meaning, (2) formulating inferences, interpretations, and reinterpretations, and (3) engaging passive knowledge and connecting it with the current situation.

*Idea Board --The Drafting Tool:* This workspace mediates a major cognitive shift in the writing process -- moving from the macro structures of thought to the micro structures of socially accepted, connected prose. Using a sequence of integrated thinking frames, this workspace breaks the process into four complex yet structured states: (1) planning, (2) visual outlining, (3) constructing paragraphs, and (4) structuring the entire paper. By foregrounding activities at appropriate times and relegating others to less prominence, the visual presentations teach student to manage the cognitive load of drafting.

*Triple Vision –The Revision Tool*: This workspace encourages the student to *re-see* a completed draft at three levels of focus: sentence, paragraph, and whole paper. Thinking frames foster strategic editing such as improving style, adding to or subtracting from the content, rearranging ideas, or completely rewriting. These more global, deep-structured editing acts are associated with higher-order intellectual activities (e.g., discerning patterns in bodies of information, exercising judgment, analysis, and synthesis).

In this study, we were interested in exploring the notion that a computerized process modeler as powerful and as eloquent as the abacus could be designed, built, and fielded for the writing process using ninth-grade basic writers as test subjects. Three research questions guided the study:

- Does a computer-mediated process-modeler improve the writing performance of ninth-graders when compared to traditional classroom instruction? Based on a standard six-point holistic scoring rubric for measurement, would the treatment group demonstrate improved abilities to produce quality writing? In short, have they become better writers?
- Does a computer-mediated process modeler improve cognitive development, as measured by four dimensions on an analytical scale when compared to traditional classroom instruction? Can we infer from textual features of the treatment group's writing that using the tool has *reorganized* rather than merely *amplified* the treatment group's abilities to perform complex, sophisticated thinking as a foundation to composing? In short, have they become better thinkers?
- Is the effect of the treatment influenced by initial writing ability? Is the computer-mediated treatment sufficiently transparent to be accessed by all subjects, or does the data indicate that measures of effect depend upon pre-existing abilities in such a way as to suggest that this cognitive facilitator requires a certain threshold of expertise to be useful? In short, is the tool only as good as its user?

### 3.0 Methods

#### 3.1 Subjects

The sample consisted of 852 ninth-grade students studying English at two demographically similar high schools in San Antonio, TX. One school (with 9 teachers, 26 classes, and 429 participating students) was designated the treatment group. The other school (with 6 teachers, 22 classes, and 423 participating students) was designated the control group. Neither group contained honors or enriched classes. Nor did the sample contain classes specifically designated as remedial. However, correlated language arts students (CLA), who in previous years would have been placed in a special class, were mainstreamed and accounted for approximately 10% of the sample.



### **3.2 Instruments**

Persuasive mode writing samples were collected from each student in the sample to baseline initial writing ability and to quantify instructional gains. The writing prompts came from the National Assessment of Educational Progress (NAEP) and were used with permission. Using prompts that had been field-tested by a national study concerned with longitudinal measurement of achievement in writing guaranteed both equivalency and test-retest reliability, as well as the absence of regional bias.

A 1-6 point holistic scoring guide, formulated by the authors, gave focus to the general impression scoring of the professional raters. This guide reduced the amount of subjectivity in the assessment by giving the raters a set of constraints and a list of features by which to determine a writer's achievement in a persuasive piece. Because the guide was an abstract description of criteria, raters were trained through the discussion of anchor papers chosen as representative types. As a result, holistic assessments were standardized against a set of papers with *known* scores.

Because the papers were judged on a rather broad set of features, the holistic assessment carried little diagnostic information. Therefore, a second rubric was designed to assess the more specific set of cognitive operations emphasized in R-WISE 1.0. This rubric (more fully described in the Discussion) outlined four subskills necessary but not sufficient for good persuasive writing. The subskills were: 1) abstraction, 2) elaboration, 3) focus, and 4) sequence. Each of these subskills was scored on a 1-4 point scale.

### **3.3 Procedure**

The study took place during the second semester of the 1992-1993 school year or from late January to late May of 1993.

**Software Design.** R-WISE 1.0 was developed and refined over a period of 12 months by an inter-disciplinary team of practitioners, researchers, and programmers supported by the Air Force's Armstrong Laboratory, Brooks, AFB, TX. A simple explanation of the composing process that has gained wide acceptance in pedagogy depicts writing as having three central stages: prewriting or invention, writing or drafting, and revision or editing. Therefore, the three workspaces of R-WISE 1.0 were created to mirror this partitioning. The teaching comes from the powers of reification (or representing complex processes as manipulable objects on the computer screen). Each of the workspaces (1) accommodates deficiencies and thereby reduces frustration for a weak writer, (2) emulates some of the crucial functionality of paper copy, (3) enriches the environment and thereby sustains motivation, and (4) models robust behaviors.

**Study Design.** A quasi-experimental contrasted groups design was used to guide data collection. It was not possible to randomly assign schools to treatment or control conditions or to randomly assign students within these groups. As a result, the groups were not necessarily equivalent at pre-test.

**Experimental Groups.** The control group received traditional classroom instruction in prose composition. As mandated by Texas curriculum guidelines, emphasis was given to 1) responding appropriately to purpose and audience, 2) organizing ideas effectively, 3) providing development for a central idea, and 4) conforming to standard syntax, usage, and mechanics.

The treatment group received similar instruction in writing, augmented by sessions on the R-WISE 1.0 tutor. The software was used in a computer lab, with 30 networked PCs arranged around the room. Each student had his or her own workstation and access to the teacher for questions. Trips to the lab substituted for classroom time periods of 55 minutes each, and were interspersed throughout the semester for a total of 8 hours in the lab-- approximately 14% of the total classroom time. On average, students went into the lab on rotations equal to once every 9 class days. In practice, more challenging assignments might have required two contiguous class periods. In any case, time in the lab was interspersed during the 16-week semester. As much as possible, time on the tutor was divided equally among the three workspaces. For more complex assignments, workspaces were conjoined; that is, the product of the drafting workspace might be read into the revision workspace. For other assignments, students took intermediate products (e.g., notecards and drafts) back to the classroom to finish the written product.

**Data Collection.** Subjects were asked to respond to two paper-and-pencil writing prompts, once at the beginning of the semester and once at its conclusion. Trained proctors provided students with standardized instructions and were present in the classroom at all times during testing.

The writing samples were scored by Psychological Corporation's Writing Assessment Center. Each paper was read at least 10 times: once by two separate raters for a holistic score and four times by two separate raters for assessment of specific subskills of the writing. Standard practice in scoring writing samples requires that two readers differ by no more than 1 point. If they do, then a third expert rater is called in to resolve the discrepancy (White, 1985). Using this criterion, composite interrater reliability scores for both pre- and post-tests ranged from .95 to .99. If we take a more rigorous approach and calculate reliabilities using the two initial ratings, interrater reliabilities drop, but are still acceptable: holistic = .79, abstraction = .66, elaboration = .63, focus = .58, and sequence = .64.

## 4.0 Results

### 4.1 Holistic Scores

Mean holistic scores, as shown in Table 1 (pg 11), revealed an unexpected trend. While treatment group scores rose by approximately 9% from pre- to post-test, control group scores dropped by about 9% over the same period. Several checks were made and additional analyses performed to identify the source of this anomaly.

First, test and implementation plans were reviewed to ensure uniformity across experimental units. We could find nothing in the design or implementation that accounted for the unexpected drop: all students received the same instructions; the same proctors were used at both test sites; and tests were given on separate but contiguous days at each school. Additional investigation ensured that each school covered basically the same curriculum; that is, they used the same texts and gave about the same number and types of writing assignments during the semester. Therefore, it is unlikely that either test administration procedures or instructional equivalency were at fault.

Next, holistic score means were calculated by teacher to determine if one or more teachers accounted for the drop in scores. Although effect sizes varied from teacher to teacher within each school, they exhibited distinct patterns across schools. The students of treatment teachers displayed no change or showed significant, positive pre- to post-test gains while the students of control teachers showed no change or significant score losses.

Finally, student aptitude differences were examined as a potential cause. Many states have instituted periodic testing of writing skills as proof of competency. In most cases, the half-way mark on a holistic scale is taken as the pass/non-pass demarcation. Therefore, we selected a similar criterion as an indicator of initial writing aptitude in this study. Thus, for this sample of Texas students, dividing the total sample based on pre-test holistic scores yields two groups, roughly equivalent to those who would have failed the TAAS (Texas Assessment of Academic Skills) and those who would have passed.

Figure 1 shows mean pre- and post-test holistic scores for all combinations of condition (i.e., *treatment*, *control*) and writing aptitude (i.e., *passing*, *non-passing*). Passing students, regardless of condition group membership, lost ground from pre- to post-test (2% vs. 14%). Non-passing students, on the other hand, showed pronounced score gains (23% vs. 6%). In both cases, treatment students significantly outperformed control students.

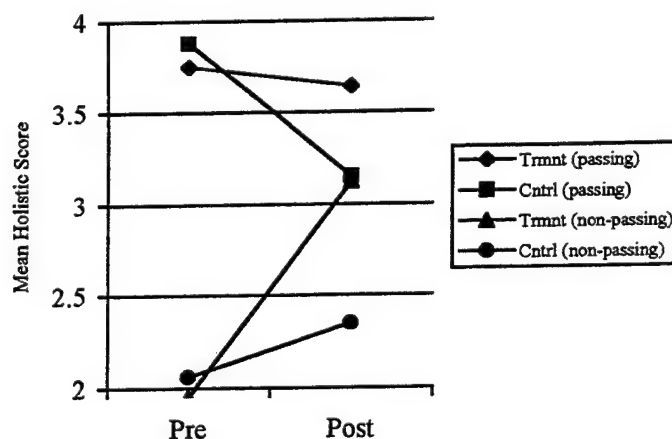


Figure 1. Holistic Scores by Condition and Initial Writing Aptitude



Table 1. Descriptive Statistics for Holistic and Analytical Assessments

	Holistic			Abstraction			Development			Purpose			Organization		
	Pre	Post		Pre	Post		Pre	Post		Pre	Post		Pre	Post	
Trmnt	m=2.97 sd= 1.11	m=3.41 s=1.20 $\Delta=.44$		m=1.93 s=.74	m=2.54 s=.74 $\Delta=.62$		m=1.93 s=.69	m=2.59 s=.67 $\Delta=.66$		m=2.19 s=.67	m=2.74 s=.61 $\Delta=.56$		m=2.14 s=.70	m=2.64 s=.67 $\Delta=.50$	
Cntrl	m=3.41 s=1.06	m=2.95 s=1.15 $\Delta=-.46$		m=2.24 s=.74	m=2.43 s=.72 $\Delta=.19$		m=2.34 s=.70	m=2.45 s=.71 $\Delta=.11$		m=2.48 s=.63	m=2.63 s=.61 $\Delta=.15$		m=2.46 s=.66	m=2.63 s=.63 $\Delta=.16$	

Note. *m* and *s* are sample mean and standard deviation.  $\Delta$  is pre- to post-test score change.

Repeated measures ANOVA was used to test the relationships between experimental variables. Based on the research hypotheses, the *condition* (i.e., treatment, control) X *repeated measure* (i.e., pre- and post scores), the *condition X writing aptitude* (i.e. passing, non-passing), and the *condition X writing aptitude X repeated measure* interactions were of experimental interest. For holistic scores, two of the three interactions were significant. The *condition X repeated measure* [ $F(1, 848) = 80.15, p < .001$ ] and the *writing aptitude X repeated measure* [ $F(1,848) = 191.58, p < .001$ ] interactions were both significant. The 3-way *condition X writing aptitude X repeated measure* interaction was not significant however [ $F(1,848) = 2.65, p = .104$ ]. The *condition X repeated measure* interaction explained about 9% of the observed variance ( $\eta^2 = .086$ ) while the *writing aptitude X repeated measure* interaction accounted for approximately 18% of the score variance ( $\eta^2 = .184$ ).

#### 4.2 Analytic Scores

Cognitive growth, as measured by the analytical scales, was less enigmatic. Table 1 (pg 11) shows descriptive statistics for the analytical assessments.

**Abstraction.** Subjects using R-WISE 1.0 gained almost 21% on this measure compared to the 6% improvement made by control subjects over the same pre- to post-test period. Percent gains for the passing-treatment, passing-control, non-passing treatment, and non-passing control sub-groups were: 11%, 3%, 34%, and 16% respectively. As suggested by these data and as shown in Figure 2, abstraction scores displayed interactions similar to those observed for holistic scores. For abstraction scores, however, the 3-way *condition X writing aptitude X repeated measure* interaction was significant [ $F(1, 848) = 6.12, p = .014$ ] although it accounted for only a small proportion of the observed variance ( $\eta^2 = .007$ ). As before, both of the 2-way interactions were significant with the *writing aptitude X repeated measure* interaction accounting for more of the score variance ( $\eta^2 = .094$  vs .046).

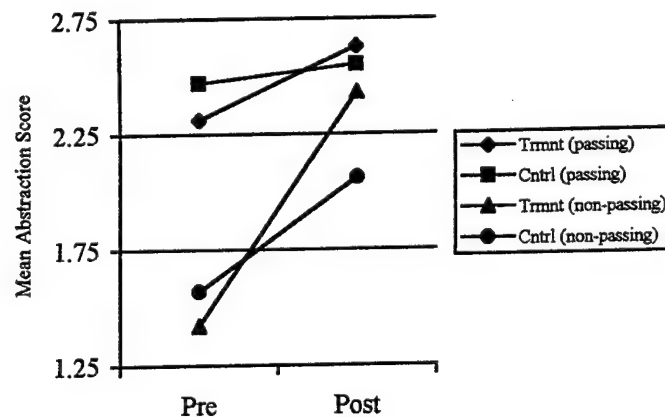


Figure 2. Abstraction Scores by Condition and Initial Writing Aptitude

**Elaboration.** Treatment students showed a 22% pre- to post-test increase on elaboration scores while the control group realized a 4% improvement over the same period. Percent gains for passing-treatment, passing-control, non-passing treatment, and non-passing control sub-groups were 13%, 1%, 34%, and 11% respectively. All 3 of the relevant interactions were significant. The 3-way *condition X writing aptitude X repeated measure* interaction shown in Figure 3,  $[F(1,848) = 11.33, p = .001]$  accounted for about 1% of the variance. This time the *condition X repeated measure* interaction was more predictive than the *writing aptitude X repeated measure* interaction ( $\eta^2 = .104$  vs  $.081$ ).

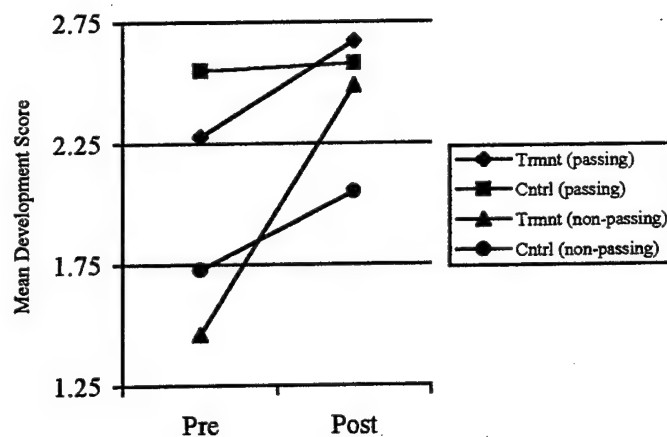


Figure 3. Elaboration Scores by Condition and Initial Writing Aptitude

**Focus.** R-WISE 1.0 subjects gained around 19% on focus scores. Control students showed a 5% improvement over the pre- to post-test period. Percent gains for passing-treatment, passing-control, non-passing treatment, and non-passing control sub-groups were: 11%, 3%, 29%, and 16% respectively. The 3-way *condition X writing aptitude X repeated measure* interaction shown in Figure 4 was not significant  $[F(1, 848) = .94, p = .332]$ . The *condition X repeated measure*  $[F(1, 848) = 46.09, p < .001]$  and the *writing aptitude X repeated measure*  $[F(1, 848)] = .94.28, p < .001]$  interactions were significant however. For focus scores, the *writing aptitude X repeated measure* effect was stronger than the *condition X repeated measure* effect ( $\eta^2 = .100$  vs  $.052$ ).

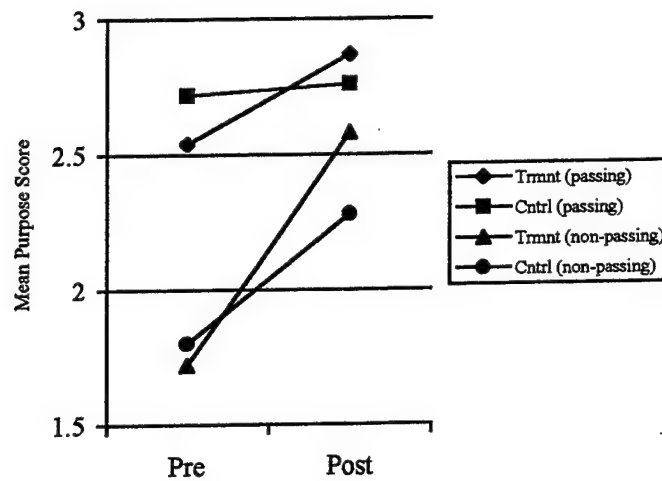


Figure 4. Focus Scores by Condition and Initial Writing Aptitude

**Sequence.** Students in the treatment condition improved 17% on the sequence score, about 12% more than those in the control group. Percent gains for passing-treatment, passing-control, non-passing treatment, and non-passing control sub-groups were 9%, 3%, 27%, and 13% respectively. The *condition X writing aptitude X repeated measure* interaction shown in Figure 5 was significant [ $F(1, 848) = 5.82, p = .016$ ] although again its associated effect size was relatively small ( $\eta^2 = .007$ ). The *condition X repeated measure* and *writing aptitude X repeated measure* interactions accounted for 4% and 8% of the score variance respectively.

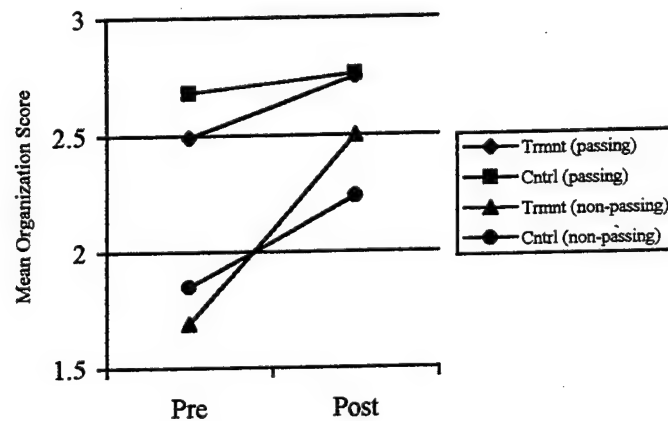


Figure 5. Sequence Scores by Condition and Initial Writing Aptitude

## 5.0 Discussion

### 5.1 R-WISE and Writing Performance

Holistic score trends (i.e., the significant condition X repeated measure interaction) suggest that not only does R-WISE 1.0 help students become better writers, but use of R-WISE 1.0 effectively supplements and extends classroom instruction in writing.

Our software follows the concept of a microworld (Papert, 1980). In other words, we conflated powerful mental operations foundational to writing into a set of manipulations and placed the visualizations in a constrained context so as to model the elaboration, state transitions, and configurations of the knowledge structures being worked within the problem space (Newell & Simon, 1972). Learners interact with the computerized environment in rich but highly defined ways. The microworld mediates learning by making choices explicit, by helping to manage the cognitive load, and by encouraging reflection during the writing process.

R-WISE 1.0 contains a *visual nomenclature* for writing whose components become synoptic overviews that trigger sophisticated cognitive actions such as formulating inferences about relationships, evoking strategies to facilitate reasoning, and prompting metacognition, or self-regulation for deploying, adapting, or abandoning sets and subsets of mental manipulations based on awareness of the situation. Rather than trivializing the task, the three tools in R-WISE 1.0 mediate four significant areas for improving instruction in writing.

- Fluid Task Representation and Adaptive Planning. Teaching novice writers to construct graphical representations for the components of a writing task helps them to gain intellectual control over a process that would otherwise remain both obscure and opaque.
- Mediating between Idea Generation and Text Production. In a composing task, ideas exist in two very different forms -- as fluid thoughts and as concrete text. Teaching students to use mediating prompts during the drafting stage increases interaction between content and rhetoric subgoals (on a cognitive level) and encourages the kind of inferencing, interpretation, and logical connections among ideas that result in higher quality student writing.
- Schema Building for Task-Types to Facilitate Text Production. Expert writers have powerful strategies for gaining intellectual control over a body of seemingly discrete data. Unfortunately, many students are never taught to develop such schema-driven strategies; they are never encouraged to extract patterns for writing tasks from one assignment to the next. Having no schema forces the student to re-invent the writing process with each new tasking. Because of this deficiency, novice student writers cannot make efficient use of their time; they frequently construct patterns based on misconceptions; and they are, understandably, frustrated by the rigors of the writing process.

- **Situational Awareness and Metacognitive Guidance.** Writing is a complex, multi-dimensional activity analogous to a contingency management problem. Good writers use an opportunistic approach; they constantly measure the emerging text against a set of expectations, while at the same time recognizing and capitalizing on serendipitous gains, weaving these *discovered* possibilities into a new rendition of the overall plan and product. Helping students to assess their audience and to understand their purpose makes it easier to calibrate among external demands, internal resources, and desired outcomes.

## **5.2 R-WISE and Cognitive Growth**

Introducing R-WISE 1.0 into ninth-grade English classes produced significant gains over and above traditional instruction on all four of the analytic measurements. If these measurements can be taken as indicators of cognitive development, then R-WISE 1.0 appears to facilitate cognitive growth above and beyond traditional methods of writing instruction.

In this study we inferred cognitive development from an examination of textual artifacts. The more common means of process research for composing are ethnographic in nature: protocol analysis, personal observation and notation, videotaping, and structured interviews, to name the more prevalent. All involve direct observation for identifying covert thinking activities that manifest themselves through specific, observable behaviors. Such methods are not without their problems. Because they are labor-intensive, sample sizes are kept small. Additionally, the procedure for scoring or interpreting episodes in the transcripts of sessions may be problematic -- as an example, how do we know for certain that a pause indicates that the writer is reflecting? And finally, the standard criticism of direct observation is that the method is intrusive and alters the very phenomena it seeks to objectively record.

On the other hand, inferring cognitive growth from text samples has a fairly long history in the study of writing. Hunt's (1977) use of T-units to assess sentence complexity is based on the notion that syntactic sophistication and cognitive growth are one and the same. Other researchers question T-units as a measure of research and point out the limitations of quantitative enumeration of surface features without concern for larger issues such as contextuality and meaning (Williams, 1979). Francis Christensen's generative approach to paragraph structure has close parallels to whole-text discourse analysis in that it accounts for units of meaning larger than a single sentence. Through a system of layering representations, Christensen (1967) devises a notation for measuring hierarchical reasoning and the logical connections through which ideas emerge and are merged into connected prose.

Other researchers also make a case for text analysis that link forms of discourse with forms of inquiry (or patterns of writing with patterns of thinking). Kenneth Pike (who, in collaboration with colleagues Richard Young and Alton Becker, advocated both a theory and a pedagogy of writing as a problem-solving process) makes a case for specific

linguistical markers as evidence that certain mental operations have taken place (Pike, 1964). Odell (1977) extends the idea that specific linguistic features are evidence that corollary types of mental operations occurred. More recently, Tamor and Bond (1983) have developed a text-analysis system that links "... task, cognitive system, and performance" (p. 113). In formulating their method, these researchers argue that explanations of text production (i.e., the cognitive dimensions) must be drawn from an examination of the text itself because -- after all -- this artifact is the item of interest in the measurement.

Our study dealt with 1,704 writing samples. Sheer volume precluded our adopting a fine-grained scrutiny of text features -- as any of the above methods would require. Therefore, we devised our second scoring instrument to directly assess text features as indicators of cognitive development. This second rubric draws from the methods of primary trait analysis (White, 1985): it has the specificity and narrowed focus of analytical scoring but the convenience of guided-holistic scoring. The instrument takes into account how well the writer understood the rhetorical situation and then deployed appropriate cognitive operations to develop a prose performance to meet these needs. Like all primary trait scoring guides, this rubric defines performance capacity as a combination of cognitive and affective maturity. We believe our rubric has merit and could be offered as an instrument for future research in which process is inferred from product.

### **5.3 R-WISE and Initial Writing Aptitude**

When the present sample was partitioned by initial achievement in writing, a reliable and significant aptitude-treatment interaction emerged across the scoring criteria. Low aptitude students using R-WISE 1.0 showed, by far, the most impressive improvements in writing performance. Gains for the upper segment of the treatment group were in the order of 9-11% while for the lower segment, the same gains were between 27-34%. Similarly, gains made by the upper segment of the control group were 1-3% while gains for the lower segment were 6-16%. Improvements made by the lower segment of the treatment group on all four analytical scales were at least double those made by both the upper segment of the treatment group and the lower segment of the control group.

In short, it appeared that students on the lower end profited more from the computer intervention than did student on the upper end. Nevertheless, in all cases but one, both segments of the treatment group outperformed both segments of the control group (on all five measures) by a factor of three. Thus, R-WISE 1.0 helped most ninth-grade writers in the sample to improve, but it was especially effective for those needing the most improvement.

With any form of intervention, persons of different abilities are differentially impacted: it is axiomatic that not all students benefit equally well from any form of treatment. Aptitude-treatment interaction (ATI) research has produced some solid results and useful insights, and will continue to grow in importance as computer-mediated instruction improves in its ability to adapt to individual learning needs and preferences (Kyllonen & Shute, 1989).

Turning to the realm of the cognitive tool in writing instruction, conventional wisdom suggests that more adept users -- that is those with more general aptitude and better domain-specific skills -- can make better use of the device and, therefore, learn more from the interaction. The converse of this reasoning prompts a belief that less adept students will benefit less from a cognitive tool. Kozma (1991) summarizes the cautions voiced in regard to using computerized instruction for novice writers.

Tools, by their nature, depend heavily on the skills of the users, yet novices bring fewer skills to the task. Furthermore, any technological intervention targeted specifically at novices must not only be effective but must also increase efficiency enough to compensate for the added cognitive burden of its own use. (p. 2)

Results from our study did not support the contention that the tool is only as good as its user. Certainly it is possible that persons with good generalized spatial and verbal ability can navigate through intricate computer interfaces more swiftly than those who must puzzle over the manipulations. Furthermore, it is probable that more adept writers have less of a learning curve in mastering a writing tool because they bring significant domain knowledge to the task and are better able to infer patterns of usage for the tool. All of these observations do not take into account the fact that integrating both principled instructional design and an active pedagogy into the tool creates an interactive device that guides the student through difficulties and grows with the learner's increased abilities.

## **6.0 Conclusions**

The current study shows persons in the treatment group of lower writing abilities achieving greater gains than more adept writers. Several explanations can be suggested for this result. First, R-WISE 1.0 has an effective instructional design founded in theory. It is transparent to the point that fledgling writers are not bogged down or required to divert cognitive energies learning to manipulate the tool itself. Second, R-WISE 1.0 worked as intended and provided the scaffolding that enabled weaker students to practice -- in a meaningful fashion -- the higher-order mental activities of good thinking. Third, motivation probably played a role in all the gains, but is more of a factor for the lower end where novelty translates into an increased focusing of activities and improved attention span. We are not prepared to make an argument for any of these three comments based on the data from the current study. Nevertheless, these issues suggest questions of interest for the design and direction of future research.



## References

- Beaugrande, R. de (1984). *Text production: Toward a science of composition*. Norwood, NJ: Ablex.
- Bereiter, C., & Scardamalia, M. (1987). *The psychology of written composition*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Bloom, B.S. (Ed.). (1956). *Taxonomy of educational objectives, Handbook I: Cognitive domain*. New York: David McKay.
- Christensen, F. (1967). *Notes toward a new rhetoric*. New York: Harper & Row.
- Cole, M., & Griffin, P. (1980). Cultural amplifiers reconsidered. In D. R. Olson (Ed.), *The social foundations of language and thought: Essays in honor of Jerome S. Bruner* (pp. 343-364). New York: Norton.
- Collins, A.M., & Gentner, D. (1980). A framework for a cognitive theory of writing. In L. W. Gregg & E. Steinberg (Eds.), *Cognitive processes in writing* (pp. 51-72). Hillsdale, NJ: Lawrence Erlbaum Associates.
- D'Angelo, F. J. (1980). *Process and thought in composition* (2nd ed.). Cambridge, MA: Winthrop.
- Eisenstein, E.L. (1979). *The printing press as an agent of social change*. New York, NY: Cambridge University Press.
- Flower, L. (1981). *Problem-solving strategies for writing*. New York: Harcourt Brace Jovanovich.
- Flower, L., & Hayes, J. R. (1980). The dynamics of composing: Making plans and juggling constraints. In L. Gregg, & E. Steinberg (Eds.), *Cognitive processes in writing* (pp. 31-50). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Flower, L., & Hayes, J.R. (1981). Plans that guide the composing process. In C. H. Frederiksen, & J. F. Dominic (Eds.), *Writing: The nature, development, and teaching of written communication: Volume 2, Writing: Process, development and communication* (pp. 109-123). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Gentner, D., & Gentner, D. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner, & A. L. Stevens (Eds.), *Mental models* (pp. 99-129). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Gentner, D., & Stevens, A. L. (1983). *Mental models*. Hillsdale, NJ: Lawrence Erlbaum Associates.

- Goody, J. (1977). *The domestication of the savage mind*. Cambridge, UK: Cambridge University Press.
- Guster, D., & Batt, R. (1989). Cognitive and affective variables and their relationship to performance in a Lotus 1-2-3 class. *Collegiate Microcomputer*, 7(2), 151-156.
- Hayes, J.R., & Flower, L. (1983). Uncovering cognitive processes in writing: An introduction to protocol analysis. In P. Mosenthal, L. Tamor, & S. Walmsley (Eds.), *Research on writing: Principles and methods* (pp. 206-220). New York: Longman.
- Hayes, J. R. (1981). *The complete problem solver*. Philadelphia, PA: The Franklin Institute.
- Hayes-Roth, B., & Hayes-Roth, F. (1979). A cognitive model of planning. *Cognitive Science*, 2, 275-310.
- Hillock, G. (1982). Inquiry and the composing process: Theory and research. *College English*, 44(7), 659-673.
- Hunt, K. W. (1977). Early blooming and late blooming syntactic structures. In C. Cooper, & L. Odell (Eds.), *Evaluating writing: Describing, measuring, judging* (pp. 91-104). Urbana, IL: National Council of Teachers of English.
- Jones B. F., Amiran, M. R., & Katims, M. (1985). Teaching cognitive strategies and text structures within language arts programs. In J. Segal, S. F. Chipman, & R. Glaser (Eds.), *Thinking and learning skills: Relating instruction to research. Vol. 1* (pp. 259-295). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Kieras, D. E. (1988). What mental models should be taught: Choosing instructional content for complex engineered systems. In J. Psotka, L. D. Massey, & S. A. Mutter (Eds.), *Intelligent systems: Lessons learned* (pp. 85-118). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Kozma, R. B. (1991). The impact of computer-based tools and embedded prompts on writing processes and products of novice and advanced college writers. *Cognition and Instruction*, 8(1), 1-27.
- Kyllonen, P. C., & Shute, V. J. (1989). A taxonomy of learning skills. In P. L. Ackerman, R. J. Sternberg, & R. Glaser (Eds.), *Learning and individual differences* (pp. 117-163). New York: Freeman.
- LeFevre, K. B. (1987). *Invention as a social act*. Carbondale: Southern Illinois University Press.

- Miller, K. F., & Stigler, J. W. (1991). Meanings of skill: Effects of abacus expertise on number representation. *Cognition and Instruction*, 8(1), 29-67.
- Newell, A., & Simon, H. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.
- Odell, L. (1977). Measuring change in intellectual processes as one dimension of growth in writing. In C. Cooper, & L. Odell (Eds.), *Evaluating writing: Describing, measuring, judging* (pp. 107-132). Urbana, IL: National Council of Teachers of English.
- Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.
- Pea, R. D. (1985). Beyond amplification: Using the computer to reorganize mental functioning. *Educational Psychologist*, 20(4), 167-182.
- Perkins, D. N. (1985, August). The Fingertip effect: How information-processing technology shapes thinking. *Educational Researcher*, 11-17.
- Perkins, D. N. (1986). Thinking frames. *Educational Leadership*, 43, 4-10.
- Pike, K. L. (1964). A linguistic contribution to composition: A hypothesis. *College Composition and Communication*, 15, 82-88.
- Rose, M. (1984). *Writer's block: The cognitive dimension*. Carbondale, IL: Southern Illinois University Press.
- Ryba, K., & Anderson, B. (1990). *Learning with computers: Effective teaching strategies*. Eugene, OR: International Society for Technology in Education.
- Salomon, G. (1988). AI in reverse: Computer tools that turn cognitive. *Journal of Educational Computing Research*, 4(2), 123-139.
- Salomon, G. (1993). On the nature of the pedagogical tool: The case of the writing partner. In S.P. Lajoie, & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 179-196). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Salomon, G., Globerson, T., & Guterman, E. (1989). The computer as a zone of proximal development: Internalizing reading-related metacognition from a reading partner. *Journal of Educational Psychology*, 81 (4), 620-627.
- Salomon, G., Perkins, D.N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher*, 20(3), 2-9.

- Schiffman, S.S. (1986). Productivity tools for the classroom. *Computing Teacher*, 13(8), 27-31.
- Smith, J. B., & Lansman, M.C. (1989). A cognitive basis for a computer writing environment. In B. K. Britton, & S. M. Glynn (Eds.), *Computer writing environments: Theory, research, and design* (pp. 17-56). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Steinmann, M. (1982). Speech-act theory and writing. In M. Nystrand (Ed.), *What writers know: The language, process, and structure of written discourse* (pp. 154-172). New York: Academic Press.
- Stigler, J. W., Chalip, L., & Miller, K.F. (1986, August). Consequences of skill: The case of abacus training in Taiwan. *American Journal of Education*, 447-478.
- Tamor, L., & Bond, J.T. (1983). Text analysis: Inferring process from product. In P. Mosenthal, L. Tamor, & S. A. Walmsley (Eds.), *Research on writing: Principles and methods* (pp. 99-138). New York: Longman.
- Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.
- White, E. M. (1985). *Teaching and assessing writing: Recent advances in understanding, evaluating, and improving student performance*. San Francisco, CA: Jossey-Bass Publishers.
- Williams, J. (1979). Defining complexity. *College English*, 40(6), 595-609.
- Zellermayer, M., Salomon, G., Globerson, T., & Givon, H. (1991). Enhancing writing-related metacognitions through a computerized writing partner. *American Educational Research Journal*, 28(2), 372-391.